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XXXIV. *On the Crystallizations observed on Glass.* By James Keir, Esquire, of Stourbridge. Communicated by G. Fordyce, M. D. F. R. S.

R. May 23, 1776. **T**HE peculiar figure of rock-crystal has been long observed. Many other substances, as spars, precious stones, pyrites, ores, metals<sup>(a)</sup>, salts, water<sup>(b)</sup>, and oil<sup>(c)</sup>, are also known to affect an uniformity of shape, when they are exposed to certain degrees of heat, cold, fluidity, and other necessary circumstances. From their resemblance in this respect to rock-crystal, they are said, when they assume their peculiar forms, to crystallize; and the regularly-shaped bodies, into which these substances concrete, are also called crystals.

(a) Native gold has been found in a crystallized form. M. ROME DE L'ISLE, in his *Essai de Crystallographie*, p. 390, says, that he has seen pieces of native gold which were eight-sided solids, like crystals of allum, and one piece which was an hexagonal plate. In Dr. HUNTER's museum, some fine specimens of crystallized native gold are to be seen. Gold may be crystallized by art also. Some æther having been poured into a solution of this metal in *aqua regia*, I observed, a few months afterwards, the gold separated from the *menstruum*, in the form of distinct polygonous prisms.

(b) The various and regular forms of the particles of snow, which is nothing else than water crystallized, are well known.

(c) The crystals, formed by cold, in the oil of saffrafras, have been observed to be very beautiful, regular, hexagonal prisms.

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In many substances, when broken, the parts appear to have some determinate figure. This determination of figure, or grain, as it is called, is obvious in bismuth, regulus of antimony, zinc, and all other metallic bodies, which may be broken without extension of parts; and although the ductility of gold, silver, lead, and tin, prevents the appearance of the peculiar grains, when pieces of these metals are broken, yet we have reason to believe, that, by exposing them to proper circumstances, they also would shew a disposition to this species of crystallization, as it may be called, by a further extension of that term; for Mr. HOMBERG has observed, that when lead is broken while hot, in which state it is not ductile, a granulated texture appears. Perhaps all homogeneous bodies, in their transition from a fluid to a solid state, would, if this transition were not effected too hastily, concrete into crystals, or bodies simularly figured. Instances of such crystallization have occurred to me in glass, which had passed very slowly from a fluid to a solid state; and the form, regularity, and size of these vitreous crystals have varied according to the circumstances with which their concretion had been accompanied. I send along with this paper a few specimens of this crystallized glass, together with a drawing of some of the most remarkable crystals.

The pieces of glass, marked N° 1. were taken from the bottom of a large pot, which had stood in a glass-house furnace at the time the fire was allowed gradually to extinguish. In this case, the mass of heated matter was so great that, without the addition of fuel, the heat con-

tinued long, and the transition of the glass from a fluid to a solid state was very slowly accomplished. The upper part of this glass was found to be changed into a white, opaque, or rather semi-opaque substance, resembling in colour and texture some of the white spars. Under this crust, which, in some places, was a quarter of an inch thick, and in others more, the glass was transparent, but considerably obscured, and its colour was changed from a dark green to a dull blue. In this semi-pellucid glass were dispersed many white, opaque, regular crystals, the form of which was generally that of a solid, whose side-view is represented by fig. 1. and whose basis by fig. 2. The surface of these crystals seems to be bounded by lines rather elliptical than circular, which are so disposed, that a transverse section of a crystal, that is, a section perpendicular to its axis, is an hexagon, as is shewn in fig. 3. and 4. the former of which represents a view, and the latter a plan, of that section. In the middle of each basis of the crystal, a conical cavity appears, as is shewn in fig. 1. and 2. The elliptical lines which bound the surface of the crystals seem to be occasioned by the edges of many thin plates, so arranged round the axis of each crystal, that their longitudinal diameters are parallel to that axis. Of these plates, twelve are larger, more conspicuous, and better defined, than the rest. They are placed in pairs, at an equal distance from each other, forming the six angles of the hexagonal section and basis, as appears in fig. 1. 2. 3. and 4. The intervals between the pairs of plates, that is, the areas of the triangles into which the hexagonal

hexagonal

hexagonal section is divided by these pairs, are filled up partly by smaller plates affixed to the sides of the principal plates, and of each other, at an angle of  $60^{\circ}$ , and partly by a substance somewhat less-opaque and darker-coloured than that of the plates. The size of the contiguous and of the neighbouring crystals does not vary much, although that of crystals, found at different depths of the same pot, were observed to differ considerably. The greatest diameter of the crystals, from which the figures 1. 2. 3. and 4. were copied, was about  $\frac{1}{10}$ th part of an inch, so that these figures represent the crystals considerably magnified. All the crystals are not by any means formed with the same exactness as those described; some having the hexagonal form less distinctly marked; but the regularity of most of them is so obvious, that no doubt can remain of the perfection of the crystallization.

Another kind of vitreous crystallization appears on the piece of glass marked N<sup>o</sup> 2. which was taken from the bottom of a pot, that had been pulled out of the furnace, while the glass was red-hot. The crystals are of two kinds; those represented by fig. 5. are of the columnar form; their altitude is about one-eighth of an inch, and the diameter of their bases about one-fifth part of their altitude; their sides seem to be irregularly fluted, or cut in grooves. The other kinds of crystals, which are represented by fig. 6. 7. and 8. have bases of nearly the same diameter as the columnar ones; but their altitude is much less, being only about one-sixth part of their diameter. Their bases are bounded by lines, seemingly

ragged and irregular; but several of them shew a tendency to an hexagonal form, the regularity of which may have been disturbed by the motion of the melted glass acting upon and bending these very thin crystals, while they were hot and flexible, at the time when the pot was pulled out of the furnace.

The specimens marked N° 3. are pieces of a glass-house pot, down the outer sides of which some melted glass had run, and adhered long enough for the formation of various kinds of crystals. The inner sides also of these pieces are covered with glass variously crystallized. Some of these crystals seem to be semi-columns, of which the flat sides, or interior surfaces, are exposed to view, and are represented by fig. 9. Other crystals, represented by fig. 10. seem to consist of several semi-columnar ones, uniting together in the same plane round a common center, like broad, flat spokes of a wheel. Many of these spokes seem to become narrower as they approach the center of the wheel, and, therefore, resemble more the segments of *frusta* of cones cut along their axis, than of cylinders. But, perhaps, this appearance proceeds only from the semi-columns being so disposed near the center of the wheel, that the edge of one is laid over the edge of the contiguous semi-column, like the spokes of a fan.

In the specimen of glass, marked N° 4. which had run through a crack in a pot, and had remained adhering to the bars of the grate of a furnace, sufficiently long for a crystallization to take place; some of the crystals appear  
oblong

oblong and needle-like, and others globular, or nearly of the globular form. In this piece of glafs, many of the needle-like cryftals are feen to unite round a common center; and although they have probably been prevented, by the too fudden cooling of the glafs, from concreting in a fufficient number to make complete globular cryftals, yet they fufficiently fhew the manner in which thofe, which are complete, have been formed. All the cryftallizations, hitherto defcribed, were obferved in a dark, green window-glafs, made at Stourbridge, and called Broad-glafs. This glafs is compofed of fand, kelp, calcareous earth, and lixiviated vegetable afhes.

Crystallizations frequently occur alfo in the glafs of which common bottles are made, the materials ufed in the compofition of which are nearly the fame as thofe above mentioned for broad-glafs, with the addition fometimes of the *fcoria* of iron furnaces. Of this kind is the fpecimen marked N° 5. in which the cryftals are not enveloped in a medium of transparent uncryftallized glafs, for the whole piece is an opaque, cryftallized fubftance; but they are prominent from the furface of the mafs. The form of the cryftals is that of the blade of a two-edged fword, whole point is truncated. In no other glafs have I feen fuch perfect cryftals as in thofe two kinds above mentioned, broad and bottle-glafs, which being more fluid and lefs tenacious, when melted, than any other, the minute particles of which cryftals confift, more eafily concrete, and apply themfelves to each other with lefs refiftance from the medium. Perhaps alfo the  
greater

greater proportion of calcareous and other earthy particles may dispose these glasses to crystallize more than others, which contain a larger quantity of saline and metallic fluxes.

Flint-glass, when long exposed to a dull red-heat, acquires a cloudiness, which, probably, proceeds from a number of small white particles, concentered by means of crystallization; but these crystals are too minute for observation. I suspect also, that the opaque whiteness, given to glass by arsenic, is the effect of a crystallization, to which this substance disposes certain kinds of glass; for the opacity given to such glass by arsenic, being greater than the opacity of the arsenic itself, cannot be communicated to a large proportion of transparent glass, merely by the mechanical interposition of this opaque, and sometimes only semi-opaque substance.

Mr. REAUMUR has observed, that some kinds of glass, by long exposure to certain degrees of heat, acquire a white opaque crust on their surface; and that this change of colour and texture, by a longer continuance of the heat, penetrates farther, till at length the whole substance of the glass is converted into a white, opaque body, which, from some supposed resemblance to porcelain, has been distinguished by the name of REAUMUR's porcelain, but is really nothing else than glass indistinctly crystallized.

Some of the properties of glass are considerably changed by crystallization; its transparency is destroyed, and it acquires an opaque or semi-opaque whiteness; its density is  
2 increased,



increaſed, for the denſity of a piece of cryſtallized glaſs was found, by experiment, to be to that of water as 2676 to 1000; whereas the denſity of a piece of uncryſtallized glaſs, which had been contiguous to the former, and conſequently had been compoſed of the ſame materials, and expoſed to the ſame heat and other circumſtances, was to the denſity of water as 2662 to 1000. The brittlenefs of glaſs is diminifhed by cryſtallization; for cryſtallized glaſs is leſs apt to crack by change of heat and cold.

Cryſtallization is always accompanied or preceded by an evaporation of the lighter and more fluid parts of the glaſs; for I found, that, by expoſing a piece of transparent glaſs till it was entirely cryſtallized, one fifty-eighth part of its weight was loſt by evaporation: and I am induced to believe, from other trials, that glaſs, which contains too large a proportion of ſaline fluxes, is leſs capable of cryſtallizing than other harder glaſſes, till it has loſt its ſuperfluous quantity of ſuch fluxes by evaporation. A doubt may therefore ariſe, whether the change of properties, induced by cryſtallization, be merely the effects of altering the texture, that is, the arrangement of the minute integrant parts of glaſs; ſince this change is always accompanied with a loſs of the lighter parts of the cryſtallizing ſubſtance. But, although a ſuperfluous quantity of ſaline or other fluxes may impede the cryſtallization, yet, that the change of properties, induced by cryſtallization, is principally or ſolely the effect of an alteration of texture, is evident from this obſervation; that a piece of cryſtallized glaſs, when expoſed to a heat  
conſiderably

considerably more intense than is sufficient merely for its fusion, and afterwards hastily cooled, loses all its acquired properties, and is again reduced to the state of transparent brittle glass, which, however, by means of the evaporation it has sustained of its lighter and more volatile parts, is rendered considerably harder, denser, and less fusible, than it was before the crystallization.

Many analogous instances might be adduced to shew how much the properties of bodies depend merely on the different arrangements of their integrant parts, or on their modes of crystallization. Thus, for instance, cast-iron and steel, when cooled suddenly, acquire a much finer grain or texture than when annealed, or slowly cooled, and are also more hard, elastic, brittle, and sonorous. From the above description of vitreous crystals we learn, that very different crystallizations occur in the same kind of substance exposed to different circumstances; and even that sometimes differently-shaped crystals are found in the same piece of glass; in which case, the circumstances must have been the same. Perhaps, indeed, the difference, observable in the shape of the crystals in the same piece of glass, may only mark the different periods in the progress of crystallization; for the crystals represented by fig. 6. 7. and 8. which are found in the same piece of glass as those represented by fig. 5. do chiefly differ from these in their altitude; and perhaps the latter kind may have been composed of a number of the former uniting by their bases. The wheel-like crystals also, fig. 10. seem to consist of several  
of

of the ſemi-columnar ones, arranging themſelves round a common center like the ſpokes of a wheel. The globular cryſtals in the ſpecimen N° 4. have been already obſerved to conſiſt of many needle-like cryſtals, converging to one central point.

Does not this diſcovery, of a property in glaſs to cryſtallize, reflect a high degree of probability on the opinion, that the great native cryſtals of *baſaltes*, ſuch as thoſe which form the Giant's Caulſeway, or the pillars of Staffa, have been produced by the cryſtallization of a vitreous *lava*, rendered fluid by the fire of volcanos?

This opinion is further confirmed by the following conſiderations. The prismatic and other regularly-ſhaped *baſaltes* have been almoſt always found to be accompanied with *lava*, pumice-ſtones, and other veſtiges of the fire of the volcanoes, whenever they have been carefully examined by intelligent naturaliſts, as has been ſhewn by M. DESMARETS, in his Memoir on the *Baſaltes* of the province of Auvergne, in France; *Mem. de l'Acad. des Sciences*, 1771. Baſaltic columns have even been diſcovered, according to the ſame author, among the productions of volcanoes now exiſting, as of thoſe of Mount Etna and of the Iſle of Bourbon.

2. The ſubſtance of which theſe baſaltic maſſes conſiſt, is generally of the ſame nature and appearance as the neighbouring and adjoining *lava*. It is generally compact, fuſible, and of various degrees of hardneſs, probably according to the matters of which the vitreous maſs was compounded. M. DESMARETS has further

observed, that the prismatic *basaltes* of Auvergne is actually a continuation, and generally the termination, of a current of *lava*.

3. Although the variety of the forms of the crystals, in the same kinds of glass, and even in the same piece of glass, which has been already remarked, sufficiently shews the uncertainty of any inference drawn from a similarity of shape; yet it may not be improper to mark the analogy, in this respect, between the basaltic and vitreous crystals. The columnar or prismatic form is known to appear most generally in the crystallized *basaltes*. Of this form also are evidently the crystals represented by fig. 5. The semi-columnar, vitreous crystals, fig. 9. seem to be analogous to the no less singular basaltic semi-columns observed in the Giant's Causeway by Bp. POCOCK (Phil. Transf. vol. XLVIII.); which, he says, were exactly like hexagonal columns cut in two. M. DESMARETS has observed, in the province of Auvergne, great quantities of spherical and ellipsoid basaltic concretions, which were formed of polygonal columns, rather pyramidal than prismatic, converging from the circumference to the center. These seem to be perfectly analogous to the vitreous globular concretions which have been above observed to be composed of oblong crystals, arranged in a similar manner. The same author also observed, in the same province, regularly-shaped tables or plates of *basaltes*; of which, he says, assemblages were accumulated in all directions. We have shewn, that the crystals represented by fig. 1. 2. 3. and 4. are

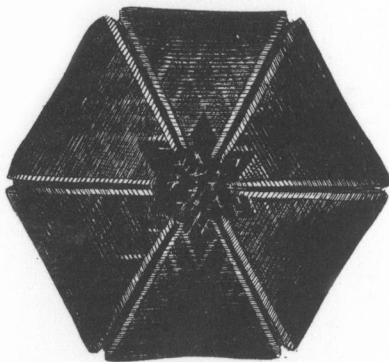
are really assemblages of plates or tables, disposed in every direction round a common axis.

Lastly, The stone on which the columns of *basaltes* generally rests, and which sometimes also is supported by these columns, being of the same nature and texture as the columns themselves, seems to be a mass irregularly crystallized, analogous to the irregularly-shaped masses in the specimens of glafs N° 1. and 2. which evidently consist of a similar substance as the neighbouring crystals, and seem to have been composed of a number of these crystals indistinctly united; for the peculiar figures of crystals are distinct only when they are insulated, or when they are separated from each other by a pellucid or differently-coloured medium. A medium of this kind appears between the vitreous crystals, and is nothing else than the more fluid parts of the glafs, which longer resist the concretion, but which, by a further continuance of the heat, would have become, with the parts already crystallized, one uniform, white, opaque substance, without any interposition of transparent glafs, or distinction of crystal, except on the surface, as in specimen N° 5, in which the crystals stand prominent from the indistinct mass, and unenveloped in any medium, in the same manner as the basaltic crystallizations appear standing above the mass of stone or *lava* which supports them.

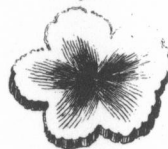
Further observations on the basaltic and vitreous crystals may probably suggest more instances of analogy

between these two substances. No just objection can be drawn against this analogy from the magnitude of the former compared with the minuteness of the latter: for the difference of size between the small vitreous crystals and the stupendous basaltic columns, which support mountains, islands, and provinces, is no more than is proportionate to the difference usually observed between the little works of art and the magnificent operations of nature.

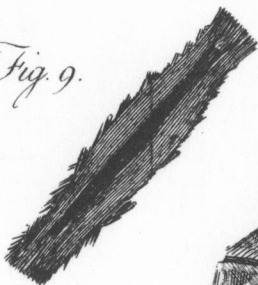
*Fig. 2.*



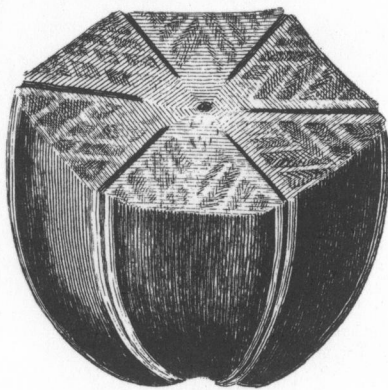
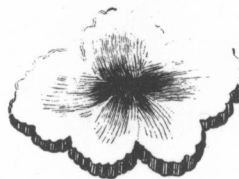
*Fig. 6.*



*Fig. 9.*

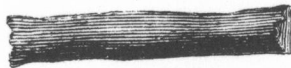


*Fig. 7.*



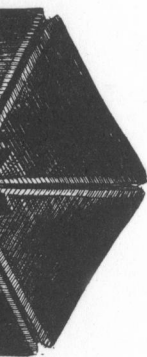
*Fig. 3.*

*Fig. 8.*

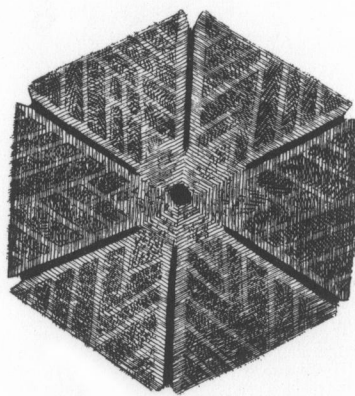
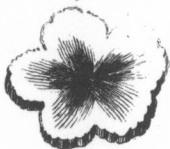


*Fig. 5.*

2.

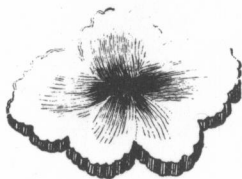


*Fig. 6.*

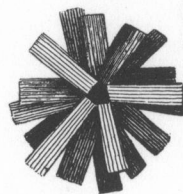


*Fig. 4.*

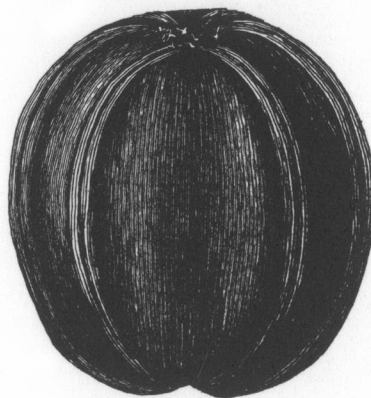
*Fig. 7.*



*Fig. 10.*



*Fig. 8.*



*Fig. 1.*



*Fig. 5.*